SIMULATION OF WHEAT CUTTING PROCESS USING THE FINITE ELEMENT METHOD

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Abstract: *The main requests that apply to cereal grains in grinding operation refer to the crushing and cutting process. This paper presents a mathematical model by the finite element method on the influence of the physical properties of a single wheat seed on the cutting process. The mathematical model for the wheat cutting process is made in order to establish the forces that appear to the first cracks of the grain, to determine the maximum force of the corn compression, the deformations of the grain resulted after the compression and the energy consumption during the compression process.*

Key words: *wheat cutting modelling, grinding process, material deformation, energy consumption.*

1. Introduction

Cutting is undoubtedly the most important technique of separating non-brittle materials and creating pieces with defined geometry [1]. The capacity of a tool before it must be honed or sharpened is related to cutting edge retention and resistance to wear and usually denoted as cutting performance [2]. Cutting performance is a function of some intrinsic properties of a knife or a blade: the alloy used for making the tool, and inclination, geometry, curvature, and the sharpened edge of the blade [3], [8].

Many foods are, however, inhomogeneous at different scale levels. They may contain particles which differ in stiffness and elasticity from the surrounding bulk material, or consist of layers which exhibit largely differing mechanical properties. As a consequence, the optimization of a cutting process must be commodity-targeted and requires specific knowledge of interactions between cutting material and cutting performance [3], [9].

During the grinding process by moving the knife edge in the normal direction, there are two distinct stages: the first stage in which the edge presses against the material, when, on the knife edge, there are normal contact pressures which produce the destruction of the integrity of the

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material [4], and a second stage, when the edge penetrates the inner part of the grain, when normal contact pressures act against the edge destroying the integrity of the material due to their value, and a second stage when the knife penetrates the inner part of the grain, causing the deformation of the material with its slanted side, pushing it aside by the wedge effect, perpendicular to the direction of movement, causing inside the material a tension which varies according to the nature of the material put under the grinding operation [9], [6].

2. Development of a Continuous Pattern of Cutting Conditions

The 3D simulation of the grinding process has as main objectives grain simulation during the cutting process. The first phase of this process is represented by the generation of the geometrical model followed by the generation of the meshed model. Between these two phases simplifying assumptions with which the model can be run, are applied [5].

The orthogonal cutting supposes that the cutting edge of the cutting tool should be placed in a position that is perpendicular to the direction of the mechanical work or movement of the cutting tool [10]. This allows us to work with forces acting in one plane.

Merchant's circle of forces is a method for calculating the values of cutting forces (F_c), tangential (F_t), the resultant (R) friction (F), normal (N), shear (F_s) involved in the process of cutting (Figure 1) in various stages of production [5].

Firstly, this will be explained using vector diagrams, followed in turn by a series of formulas and the resulting diagram will be shown in Figure 1.

3. Wheat Cutting Simulation Process

The analysis allows determination of tensions, deformations and forces located in the structures of cutting knife and material undergoing due to the tasks resulting from the cutting operation. Load condition which can be applied in the analysis is determined by concentrated or distributed outside forces imposed by a law, applied to the cutting edge of the knife and work surfaces [10].
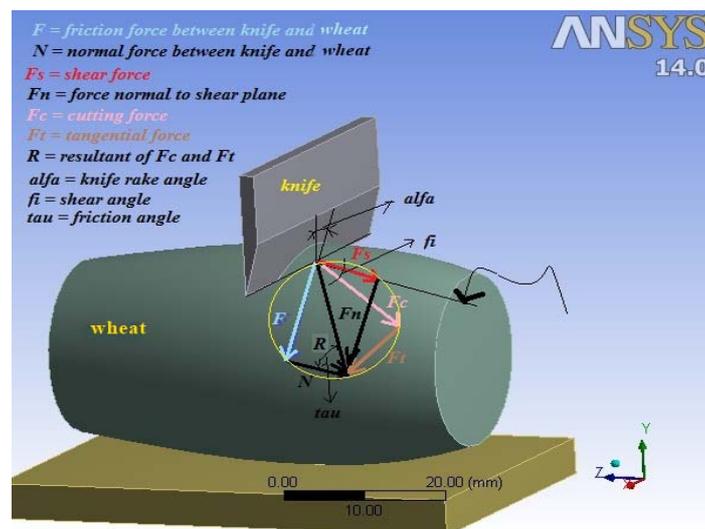

Fig. 1. *Merchant's circle of forces*

According to the study carried out using the finite element method, the basic concept is the analysis of the geometric structure model, which is a set of discrete elements, connected together by a finite number of nodes. The operation of creating such a network is known as meshing.
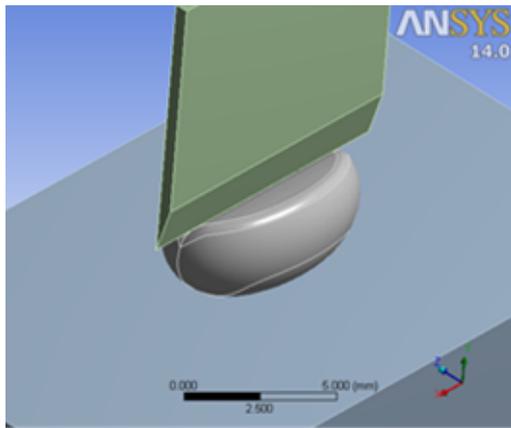

Fig. 2. *The geometrical considered model of the analyzed products*

Cutting vegetables products with large deformations is a process involving major plastic deformation of the material in a restricted area and incorporates many significant events, such as tearing, agglutination and sliding friction or efforts localization [11].

These conditions increase the difficulty of the simulation process. The problem of the first works in this area was to find a suitable algorithm for modelling material separation in the blade area. Most of the works were based on a Lagrangean perspective where the finite element network is attached and moves simultaneously with the material in space. In order to simulate splitting, the knife moves along the sample describing a "parting line", defined previously, and the nodes in front of the cutting tool are separated into two when separation condition is accomplished. In other words, the complexity of simulations with finite element method (FEM) will increase significantly when the dynamic nature of the cutting process is included in the simulation [7]. Figure 3 represents the simulated cutting process configuration.
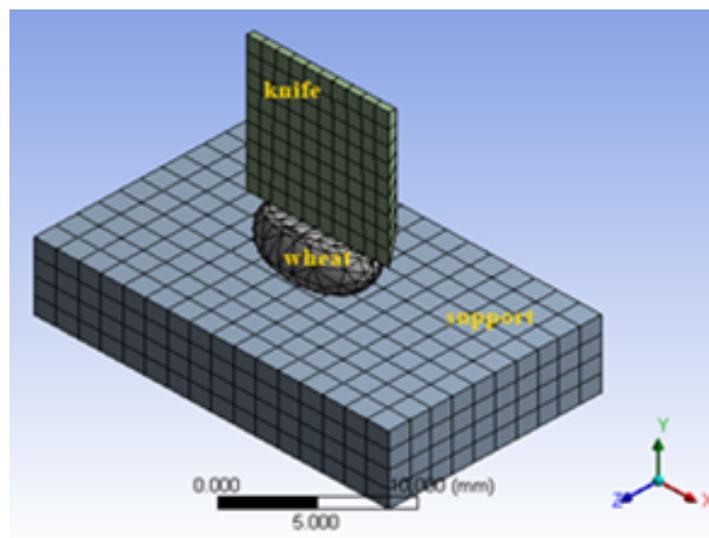

Fig. 3. *The configuration of the simulated cutting process*

An efficient algorithm is used for computing numerical soft tissue deformation specific to vegetables, simulating cutting applications in real time. The algorithm is based on the finite element method using the Lagrange method, where the efforts and deformations are measured according to the original configuration. A default method was used, because the answer to the current time step depends not only on previous information, but the current information. The algorithm is able to monitor the nonlinearities of the material or geometric nature.

The knife is considered a relatively rigid body, with a high elasticity modulus and an acute angle of 15°, a curvature of the corner is the radius of curvature of the cutting edge. Cutting force of the grain of wheat is required to be about 23 N.

In this simulation, it has been considered as a radius of curvature the value of 0.25 mm of the edge of the knife. Wheat sample is a truncated ellipsoid with maximum radius of 1.5 mm and a length of 6 mm.

The geometry of the sample is chosen to be simulated in an orthogonal configuration cutting. The cutting tool and the sample are modelled as deformable objects and at their interface there are contact elements inserted to represent the contact between them.

These elements prevent penetration and transmit forces between the surfaces of the bodies. To illustrate the slipping or sticking of the fragments on the faces of the tool a speed-dependent friction model is given [11].

With the advance of the knife in the processed product during cutting, the elements near the top are crushed and highly distorted because the tool penetrates into them. This creates a major problem of convergence, and, if not prevented, the solution will be prematurely dropped.
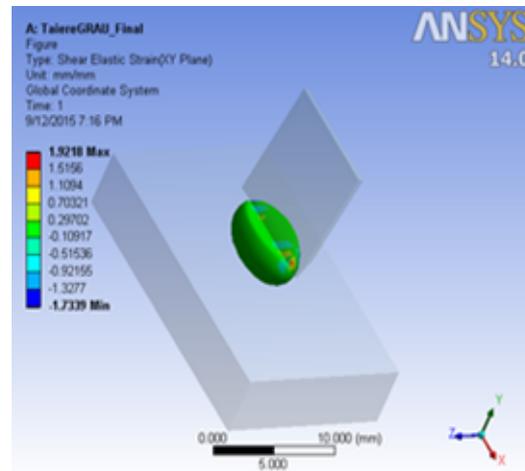

Fig. 4. *Elastic deformation contour in XY cutting plane*

In the processing stage the type of analysis that is going to be used is primarily chosen, a transient analysis being selected. For models with many degrees of freedom as the case of this simulation, the direct solving methods used for the system of equations will generally require a lot of memory. In post-processing stage plots of selected sizes for storage in the previous phase are performed and their values are listed.
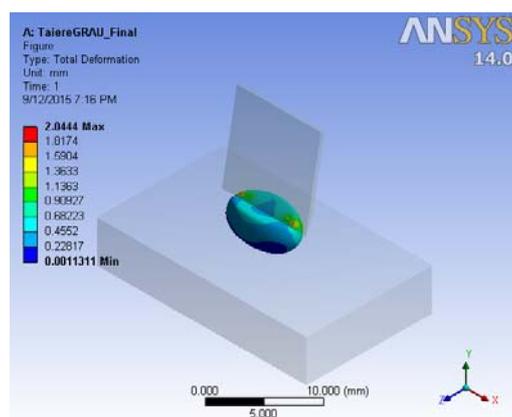

Fig. 5. *The deformation occurred in material mass*

The graphical presentation is designed in contours. Each shape has a certain colour and

represents the geometric model region where the size has the value described in the legend of colours, attached to the graphical representation. In the following figures are represented the results obtained from simulations with the finite element method.
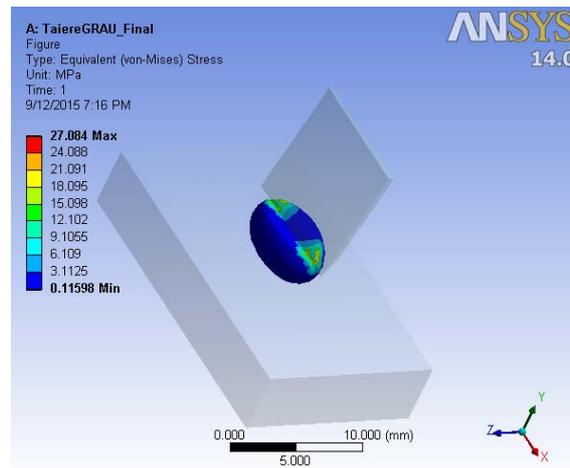

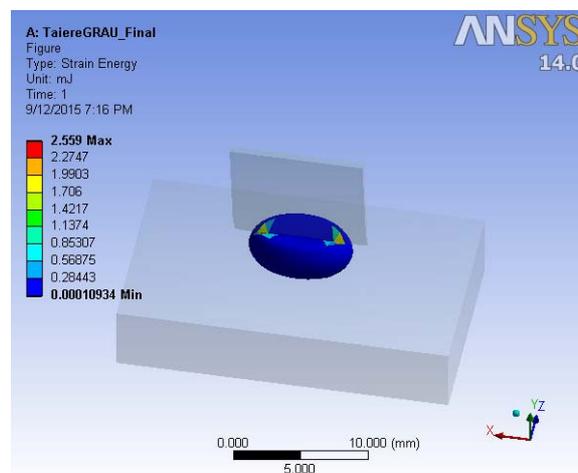Fig. 6. *The values of the equivalent tensions to cutting the wheat grain*

Fig. 7. *Cutting energy values of wheat grain deformation*

4. Conclusions

Cutting vegetable products with large deformations is a process involving major plastic deformation of the material in a restricted area and incorporates many significant events, such as tearing, agglutination and sliding friction or localization efforts. These conditions increase the difficulty of simulation the process.

The analysis allows the determination of tensions, deformations and forces localised in the structures of the cutting knife and material undergoing, due to the tasks resulting from the cutting operation. Load

condition which can be applied in the analysis is determined by concentrated or distributed outside forces, according to an imposed law and applied to the cutting edge of the knife and work surfaces.

Simulations have been focused on cutting the individual grains of wheat, in order to obtain a comprehensive model that can estimate the real effects of various parameters cutting process stability.

According to the morphological structure of the material cutting is performed with or without cracks in the material. Cracks propagate quickly and branches, in the direction of movement of the knife.

The amount of effort invested in the first phase depends on the initial state of the material (the humidity), and in the second phase depends on the native structure of the material.

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